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Determination of Geometrical Track Position by Robotic Total Station

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Abstract

Robotic total stations belongs to the most innovative and advanced geodetic instruments used in engineering practice with the performance to maximize productivity and to accomplish requirements concerning to the high angle and distance precision. Robotic Total Station Trimble S8 was used for precise terrestrial measurements of railway track built on ballast-less track construction to diagnose the track behaviour under traffic loading.

Keywords: robotic total station; geometrical track position; ballast-less track; terrestrial measurements.

1. Introduction

Modern geodetic terrestrial technology involves automatized observations based on an application of robotic total stations. The benefit of such an advanced geodetic instrument is in its high precision sustainability, manipulation simplicity, maximum flexibility, one-person operability and personal error reduction. The paper is devoted to the analysis of results achieved by using such a modern geodetic instrument in the process of diagnostics of the geometrical position of a new track construction built in the frame of modernisation of Slovak railway.
The main purpose of railway modernisation is in increasing the railway speed, which predicts to design the new railway line constructional and geometrical parameters. In the frame of such a railway reconstruction, ballast-less

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track construction was built in the locality of tunnel *Turecky vrch,* which is laying in the north-south part of Slovak railway corridor. The diagnostics of the ballast-less track construction (BTC) requires its regular monitoring by both of relative and absolute technologies. The relative technology is realized by special railway facilities, which determine the geometrical track parameters in their relative position. The absolute technology is based on geodetic observations, which determine the ballast-less track position in dependence on positional reference network defined in national coordinate system.

Nomenclature

BTC	ballast-less track construction
ΔZ	real positional displacement
Δz	measured positional displacement
$\varepsilon_{\Delta z}$	real error
σ_{zi}	random standard deviations
t_{α}	coefficient of Student distribution

2. Railway Structure Specification

Reconstruction of the north route of railway line from west to east Slovakia has brought the new unconventional type of railway structure, ballast-less track RHEDA 2000, based on continuous reinforced concrete slab, which has been situated in the 2 km long tunnel part laying between towns *Trencin* and *Nove Mesto n/Vahom*. The experimental location is situated in the both sides of railway tunnel (Fig. 1), beyond railway bridge and in the place of transient sections between the ballast-less and traditional track structure to verify the possible track geometry changes caused by traffic loading.

a) b)

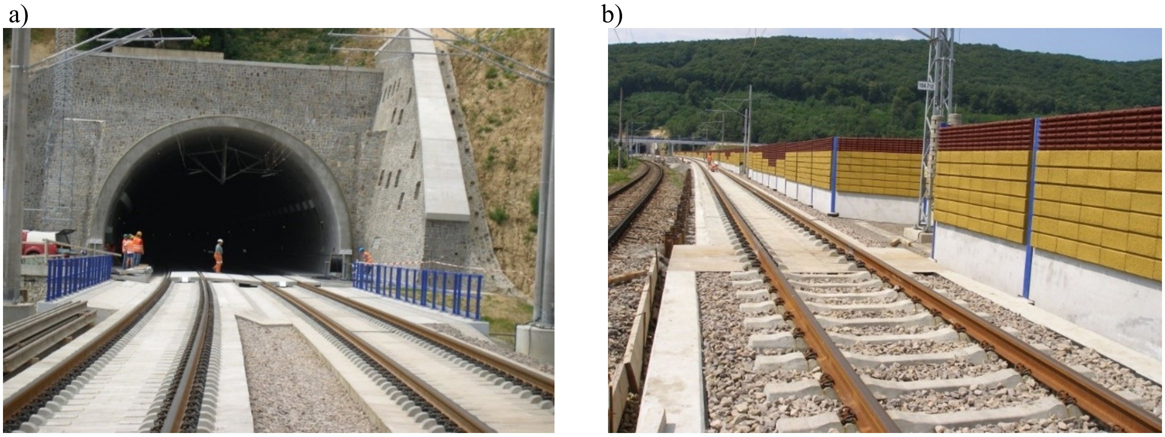

Fig. 1 a) Ballast-less track in the tunnel b) Transient section between ballast-less and traditional track construction.

However, Slovak Railways regularly perform track inspection and maintenance by variety of specialised railway facilities, geodetic measurements are needed for monitoring the track structure to diagnose its possible deformation and straining caused by traffic loading and to prevent the track permanent deformation, which could bring track geometry changes and consequently, increase the traffic loading efficiency.

3. Geodetic observations

The main task of terrestrial geodetic measurements is to control the positional and height stability of ballast-less track in a period of five years. Since, three epochs of geodetic measurements have been realized separately positional and height one. Height measurement has been performed by the precise levelling technology and the positional observations by robotic total station TRIMBLE S8. Because of the wide problem, the main task of this publication is to analyze outputs of positional geodetic observations especially from the point of reached accuracy.

TRIMBLE S8 is video-assisted robotic total station utilizing Trimble VISION technology, which means that it sees everything without a trip back to the instrument and select targets with just a tap of the controller screen. So, measurements are drawn to the video image and surveyor can be certain to never mess a shot he needs. The total station involves also Trimble FineLock technology to detect targets without interference from surrounding prism and Trimble SurePoint accuracy assurance to correct instrument pointing.

The a-priori precision of TRIMBLE S8 is involved in its technical parameters and is defined by producer with the following values:

- angle accuracy: 0.3 mgon,
- distance measurement accuracy in standard prism mode: 1 mm + 2 ppm,
- distance measurement accuracy in tracking mode: 4 mm + 2 ppm.

Geodetic observations of ballast-less track were realized in standard prism and tracking mode and the track position was defined relative to railway benchmarks in the national coordinate system. The measurements have been realized in successive cycles (epochs), whereby the first measurement has been performed just after railway building acceptation.

Organization of a measurement epoch consists in observation of both of rails from the free station position under traffic closure. The experimental locality was exactly in kilometrage stationing 102.360-102.530 in the south part of tunnel and 104.200-104.820 in the north part of tunnel. The particular points were signalized each eighth sleeper (it is about 5 meters) by the marks drawn on the concrete sleeper.

4. Analysis of measurements

Diagnostics of geometrical track position assumes also to determine the longitudinal and transversal changes of the track axes, which is monitored in particular measurement epochs. For the reason, the geodetic observations were pointed to the right rail of railway line the axes position was defined in post-processing by offset regime. For the purpose to eliminate the target-centering error, co-ordinations of the particular points were converted into projected system by using track-projected parameters. The track positional changes or displacements were then determined by comparing the point co-ordinations with the appropriate one observed in another epoch.

The analysis of track positional changes belongs to the statistical analysis testing based on postulate of null hypothesis:

$$H_0 : \Delta Z = 0\,,\ \Delta z = -\varepsilon_{\Delta z} \tag{1}$$

where the real positional displacement is a function of real observation errors $\varepsilon_{\Delta z}$

$$\Delta Z = \Delta z + \varepsilon_{\Delta z} \tag{2}$$

and the measured displacement in both of epochs Δz :

$$\Delta z = z_2 - z_1 \tag{3}$$

Suppose, the measured values are normal distributed $N(\Delta Z, \sigma^2_{\Delta z})$ and also the measuring errors will be normal distributed $N(0, \sigma^2_{\Delta z})$, the confidential interval for measured displacement can be defined as follows:

$$P\left(\left|\varepsilon_{\Delta z}\right| > t_\alpha \sigma_{\Delta z}\right) = P\left(\left|\Delta z\right| > t_\alpha \sigma_{\Delta z}\right) = \alpha\,, \tag{4}$$

where $\sigma_{\Delta z}$ is random standard deviation depended on random variances of both of observation epochs:

$$\sigma_{z1i} = \sqrt{\sigma_{z1}^2 + \sigma_{zi}^2} \tag{5}$$

In practice, the hypothesis testing of a point positional displacement can be realized by the common convention defined by following inequalities:

If $|\Delta z| < \sigma_{\Delta z1i}$ *null hypothesis is accepted and a point displacement is not evident.*

If $\sigma_{\Delta z1i} \le |\Delta z| < 2\sigma_{\Delta z1i}$ *a point, displacement is possible.*

If $|\Delta z| > 2\sigma_{\Delta z1i}$ *null hypothesis is not accepted and a point displacement is evident.* (6)

Following graphs displayed in fig. 2 and fig. 3 represent the differences between measured data and projected one of both of railway lines determined by three measurement epochs:

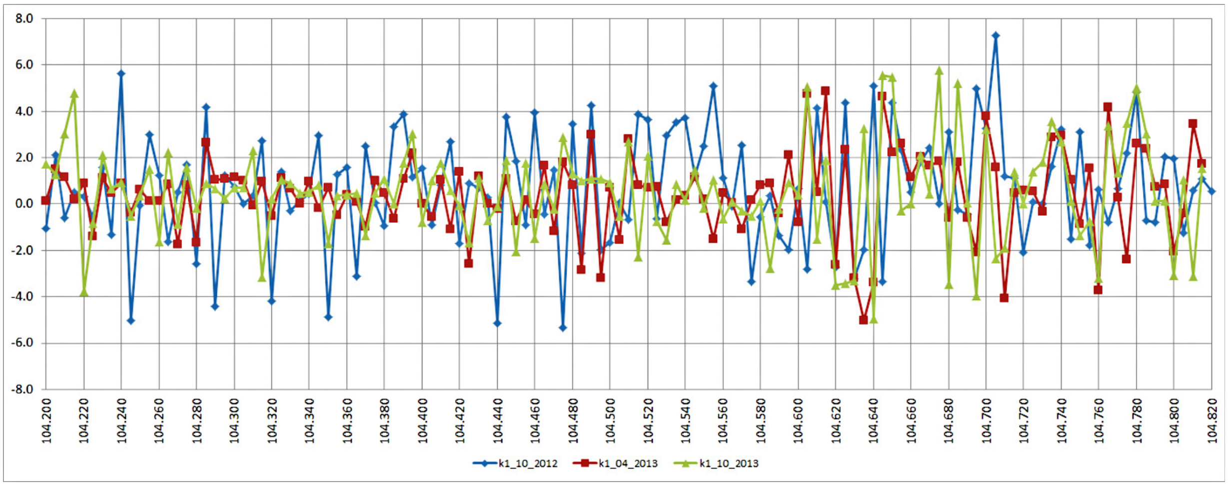

Fig. 2 Differences between measured data and projected one of ballast-less track 1.

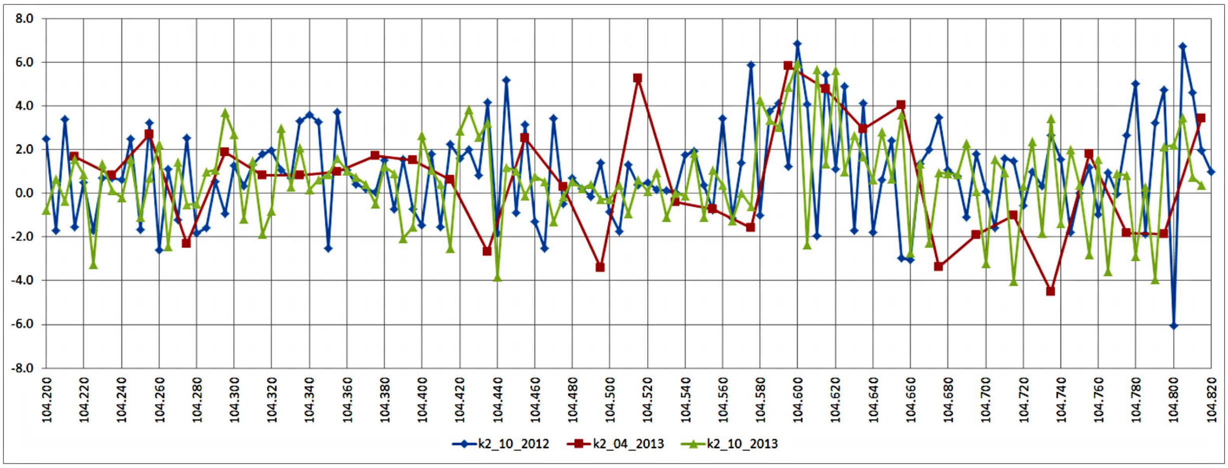

Fig. 3 Differences between measured data and projected one of ballast-less track 2.

The precision of measured values is defined by a-posteriori standard deviations evaluated in each of three epochs, which have the followings values:

$$\sigma_{z1} = 4.4\ \text{mm}, \sigma_{z2} = 3.9\ \text{mm}, \sigma_{z3} = 4.2\ \text{mm} \tag{7}$$

The precision of the displacement between the first and second epoch σ_{z12} and the first and third epoch σ_{z13} is then evaluated according to the formula (5):

$$\sigma_{z12} = 5.9\ \text{mm}, \sigma_{z13} = 6.1\ \text{mm} \tag{8}$$

Implementing the hypothesis testing explained in equations (6) the positional changes of ballast-less track are not confirmed as we can see in fig. 4 and fig. 5.

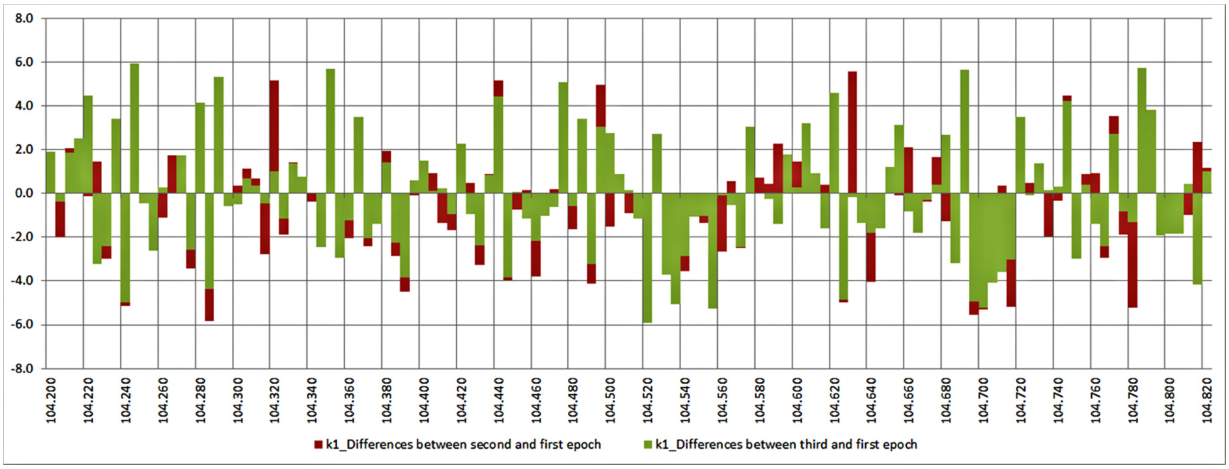

Fig. 4 Transversal displacements of ballast-less track 1 between 1st and 2nd epoch.

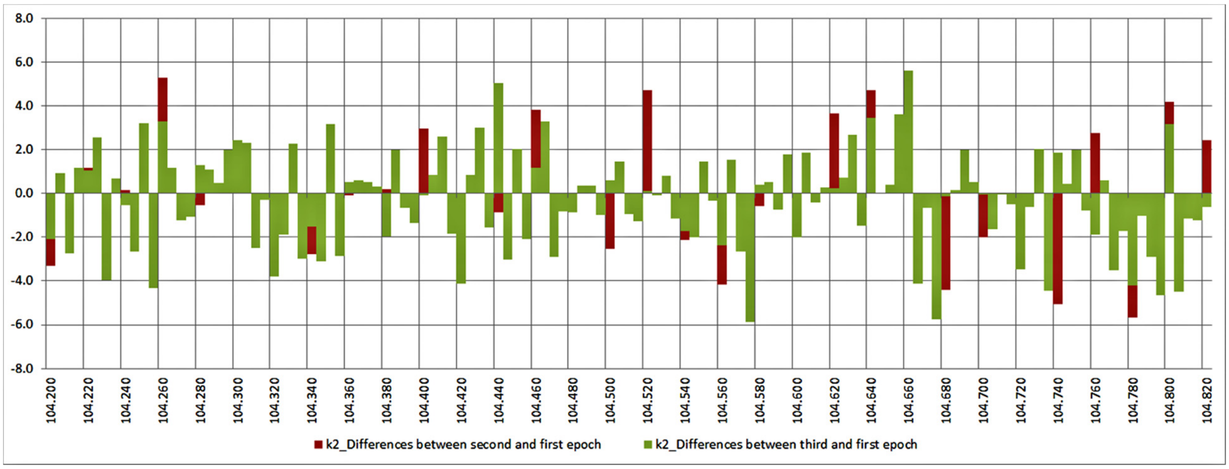

Fig. 5 Transversal displacements of ballast-less track 2 between 1st and 3rd epoch.

5. Conclusions

Standard deviations of measured transversal displacement σ_{zi} accounted in equations (8) represent the precision of determination of transversal displacement of both of track and involves the error of multitrack target positioning in regard of track axis (± 2 mm) and precision of displacement estimation process (± 2-3 mm). The longitudinal displacement of ballast-less track was not evaluated, because of the fact that precision of multitrack target positioning in longitudinal direction of track is out of assumed value of longitudinal displacement. The main problem, which starts up during the up to now observations in all of epochs seems to be in permanent signalization of the particular points on the ballast-less track construction to minimize the error of reflector target positioning. As we can see in fig. 4 and fig. 5 the transversal displacement of ballast-less track was not confirmed and the estimated values are in the frame of measuring errors.

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